GSI - 86 - 2
REPORT
APRIL 1986
ISSN:0171-4546

PERFORMANCE OF THE OXYGEN INJECTOR FOR THE CERN LINAC 1

B.H. Wolf, K. Leible, P. Spädtke, N. Angert, J. Klabunde, B. Langenbeck,
R.A. Gough, J. Staples, R. Caylor, D. Howard, R. MacGill, J. Tanabe

Gesellschaft für Schwerionenforschung mbH
Planckstr. 1 · Postfach 11 05 41 · D-6100 Darmstadt 11 · Germany

Performance of the Oxygen Injector for the CERN Linac 1 +

B.H. Wolf, K. Leible, P. Spädtke, N. Angert, J. Klabunde and B. Langenbeck
GSI, D-6100 Darmstadt, Fed. Rep. of Germany

R.A. Gough, J. Staples, R. Caylor, D. Howard, R. MacGill and J. Tanabe
Lawrence Berkeley Laboratory, Berkeley, California 94720, USA

Summary

An injector system has been constructed to provide an oxygen beam for the CERN accelerators. An ECR source produces an O^{6+} ion beam, which is accelerated in an RFQ structure from 5.6 keV/u to 139.5 keV/u. The specifications of this preaccelerator are described and results of test measurements at GSI are presented. The oxygen injector is now installed at CERN. Preliminary experiences with oxygen and α-particles are given.

1. Introduction

A GSI-LBL-Heidelberg-Warsaw-collaboration proposed an experiment for the study of relativistic nucleus-nucleus reactions induced by ^{16}O-beams at the CERN PS in 1982[1]. After study of its implications to the PS machines[2], this proposal was accepted in 1983. For the generation and acceleration of the heavy ions, a collaboration was then established among CERN, GSI and LBL. Fig 1. shows a general view of the accelerators involved.

For the proposed experiment the projectile nucleus should be as heavy as possible. However, as the CERN PS complex was not designed for heavy ions, the choice of ion species was restricted by the given boundary conditions,such as the accelerating field levels in the linac and the lower current limits for controlling and monitoring the existing ring accelerators. From all possible candidates for heavy ion acceleration, until now only O^{6+} from an electron cyclotron resonance (ECR) ion source met these boundary conditions.[3] However,

----

+The LBL portion of this work was supported by the Director, Office of Energy Research, Office of High Energy and Nuclear Physics, Nuclear Science Div., U.S. Dept. of Energy under Contract No. DE-AC03-76F00098.

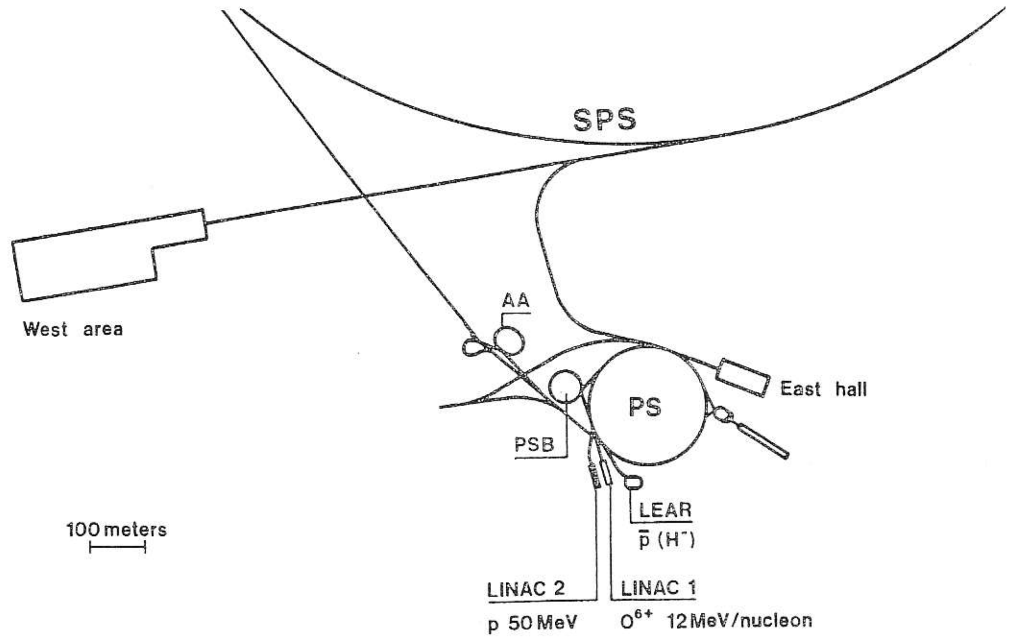


Fig. 1: Layout of the accelerator complex for the relativistic ^{16}O beam

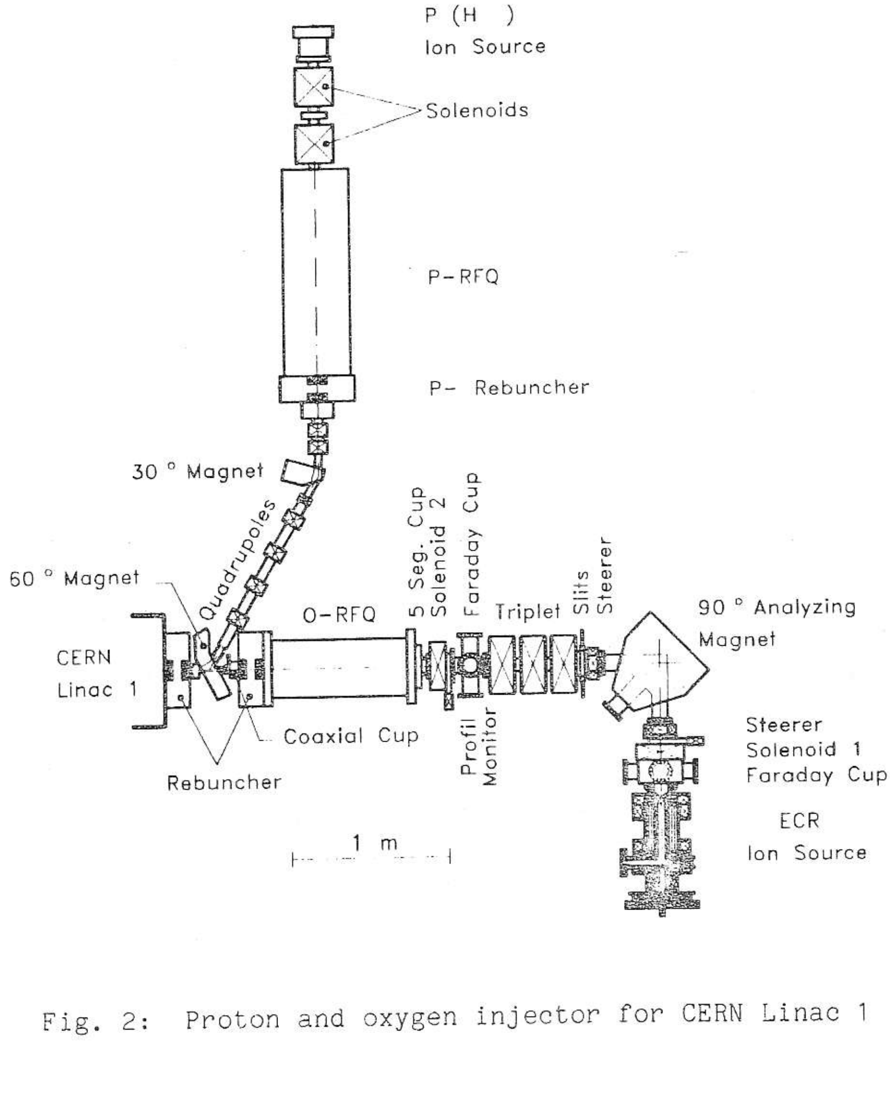


Fig. 2: Proton and oxygen injector for CERN Linac 1

with an upgrated ECR ion source it seems to be possible to accelerate even heavier species, such as Ne^{8+}, Mg^{9+}, S^{12+} and Ca^{15+}.[4,5]

The $^{16}O^{6+}$ ions are generated and preaccelerated to 139.5 keV/u in an injector, which is described in this report, and then further accelerated in the Linac 1 ("Old Linac") to 12.5 MeV/u. At the Linac 1 exit, they are fully stripped for further acceleration in the booster rings, the PS and finally the SPS. The PS and SPS provide maximum energies of 7 and 225 GeV/u for N = Z projectiles. About 10^8 particles will be accelerated per overall cycle of about 14 s, and extracted from the SPS during a flat top period of about 3 s.

External beams are simultaneously available in the North and West experimental areas, at 60 to 225 GeV/u and with intensities varying from 10^5 to $3 \cdot 10^7$ particles per second in different beam lines.[5] The beam emittance is below 1 π mm mrad. Five major experiments have been approved at this time for the two 18-day runs in 1986 and 1987.

2. Oxygen Injector Design

The oxygen injector consists of an ECR ion source, a low energy beam transport system (LEBT) for charge and mass analysis, a radio frequency quadrupole (RFQ) accelerator and two rebuncher cavities (Fig. 2). A 60° inflector magnet between the two bunchers enables the injection of protron or H^- beams from a separate injector.

2. a) ECR ion source

The oxygen ions are generated in a two-stage ECR ion source of the MINIMAFIOS type (Fig. 3), purchased from R. Geller, CEN-Grenoble.[4,6] The source is driven with an RF power of about 1 kW by a 10 GHz transmitter in a pulsed mode (pulse length 30 ms, pulse rate 0.83 Hz). The oxygen gas is fed into the first stage of the ion source and controlled by a needle valve at high potential. Helium is added as a support gas to improve the O^{6+} output of the source. The helium is fed to the second stage through a remote controlled valve on ground potential.

To reach the resonance condition for the electron cyclotron heating and to obtain confinement of the ions for the production of high charge states, a special magnetic field configuration is used in the MINIMAFIOS ion source. This magnetic field is provided by a set of coils for the mirror field,

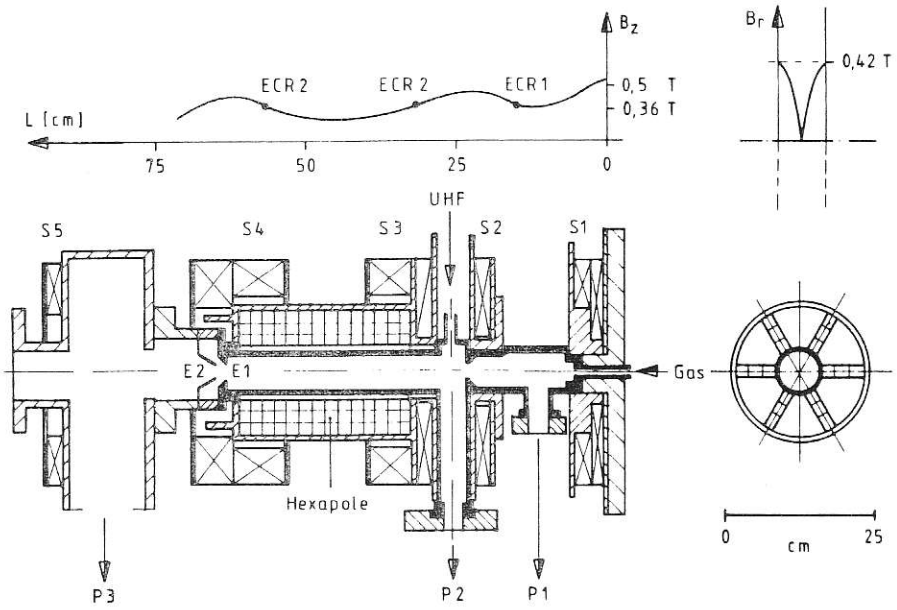


Fig. 3: ECR ion source MINIMAFIOS with distribution of the magnetic field. E_1, E_2 extraction system; S_1 - S_5 coils for mirror field; P_1 - P_3 turbomolecular pumps; UHF 10 GHz microwave feed.

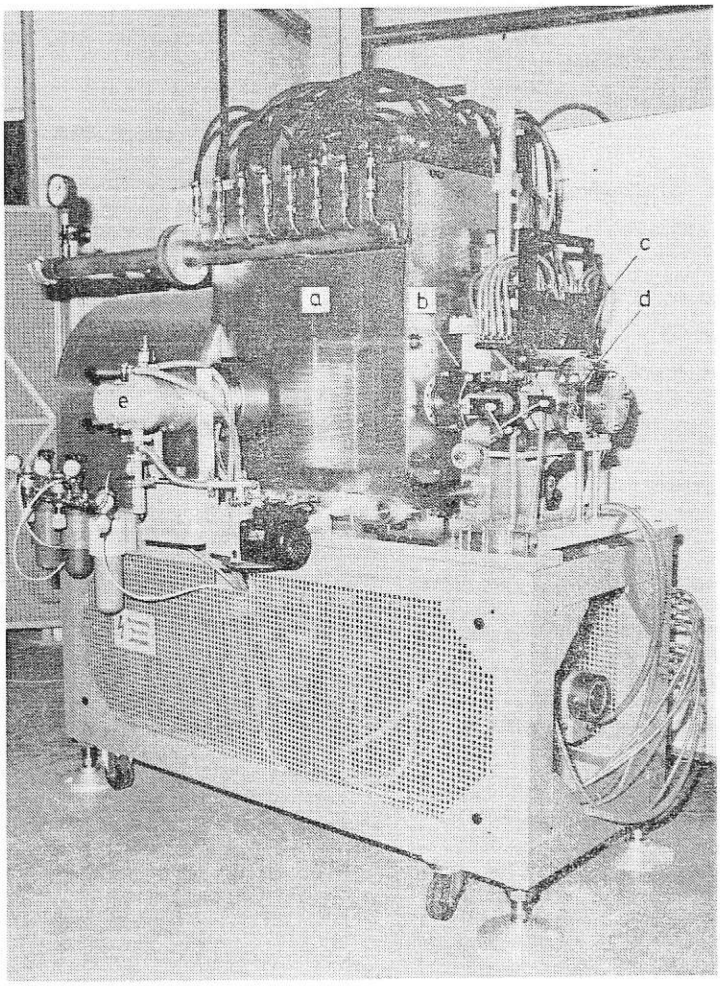


Fig. 4:
a) ECR ion source
b) Extraction
c) Solenoid
d) Steerer
e) Pump of the first stage

powered with ca. 100 kW (45 V 1150 A) and by Samarium-Cobalt permanent magnets for the hexapole field (Fig. 3). The ions are extracted from the source with 15 kV through a 7 mm Ø hole with an extraction electrode of 13 mm Ø over a gap width of 30 mm. The design current was 80 eμA of O^{6+} within an emittance area of 200 π mm mrad. Three 170 l/s turbomolecular pumps at the source and two 330 l/s pumps behind the extraction provide a base vacuum of 10^{-7} mbar. The operating pressure in the source is approximately 10^{-5} mbar, while the pressure in the extraction is better than 10^{-6} mbar. To keep the magnetic field undisturbed, the ion source is mounted on an aluminum stand, which supports all parts at high potential (15 kV). Thus the complete outer surface of source and support structure could be connected to ground potential (see Fig. 4).

2. b) Low Energy Beam Transport

The function of the LEBT is to separate the O^{6+} ions and to adjust the oxygen beam parameters to match the RFQ acceptance. That means 290 π mm mrad at 5.6 keV/u for the O^{6+} beam extracted from the ECR source with an extraction voltage of 15 kV. A schematic of the different elements is shown in Fig. 2. The oxygen ion beam from the source is matched by a solenoid to a double-focusing 90° bending magnet. After the bending magnet, the selected O^{6+} beam is matched by a quadrupole triplet and a second solenoid to the RFQ. The RFQ structure requires a strongly-convergent, round beam (0.15 rad). The beam envelope in both the horizontal and vertical planes is shown in Fig. 5.

The solenoids have a bore diameter of 80 mm and consist of a coil (made from water-cooled copper 5 x 5 mm²), two mirror plates and an iron yoke. At full power of 11.5 kW (420 A and 27.5 V) they produce a magetic field on axis of 5 kG as shown in Fig. 6. In operation, the first solenoid is set to 35 %, the second to ca. 80 % of the maximum value. This agrees with calculated values (Fig. 5). With 4 kG in the second solenoid the almost parallel O^{6+} beam (15 kV) is focused to the RFQ entrance in a distance of 14 cm.

The 90° analysing magnet has a bending radius of 25 cm, a gap width of 70 mm, and an entrance and exit pole face angle of +16°. The maximum field is 4 kG at 240 A and 35 V. For the 15 kV O^{6+} beam, the field is only 1.15 kG.

The quadrupole triplet serves to correct the difference in vertical and horizontal focusing of the 90° magnet, and to match the beam to the second solenoid. The field gradient is low (28 kG/m) and the coils (powered with 12 A, 11 V) are air cooled. The length of one pole is 89 mm and the

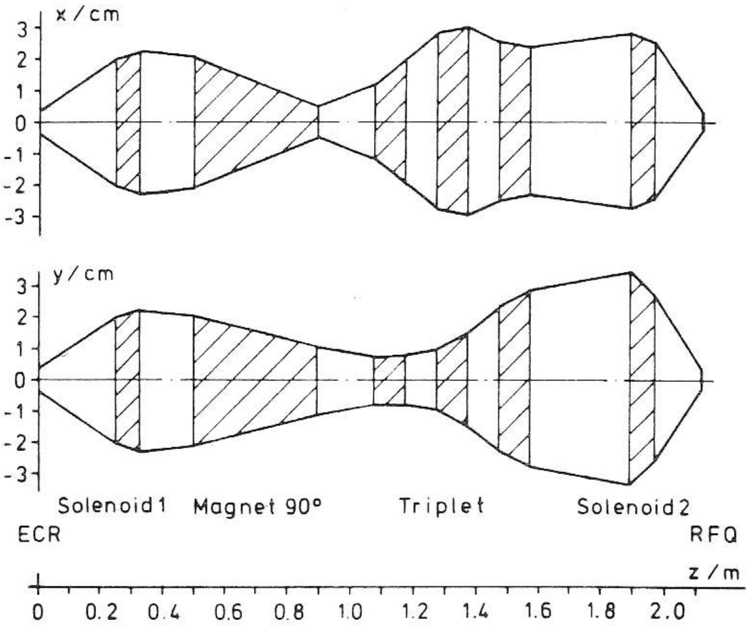


Fig. 5: Calculated LEBT beam envelope in horizontal and vertical planes

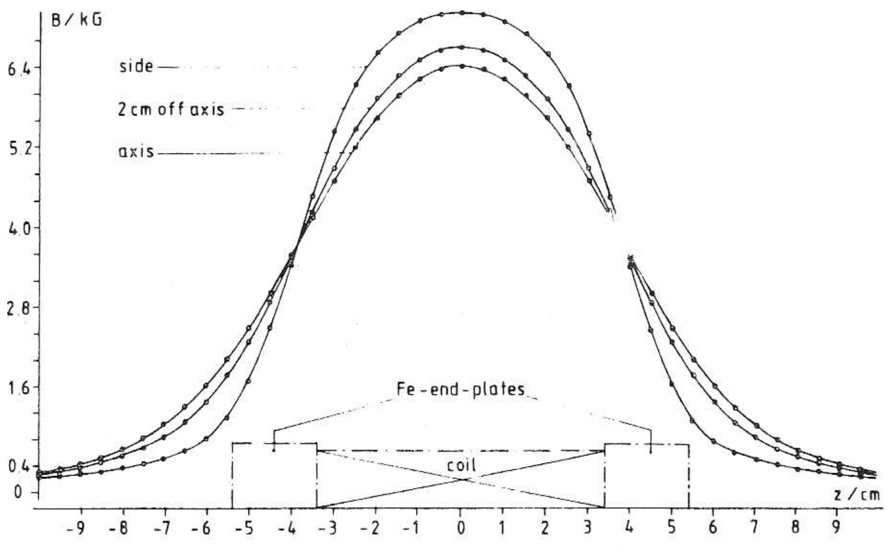


Fig. 6: Magnetic field distribution of solenoids at maximum power (11.5 kW)

aperture 80 mm Ø. Two sets of steering magnets are mounted over the bellows before and after the 90° magnet. The size is ca. 100 mm x 100 mm x 40 mm, and the maximum field is 80 G, enough to steer the beam over ± 20 mm at the RFQ entrance.

A pair of horizontal and vertical slits after the analyzing magnet facilitates both alignment and ion separation (especially N^{5+} from O^{6+}). A beam diagnostic box with a faraday cup and a grid type profile monitor is positioned between the quadrupole and the second solenoid. A 5-segment faraday cup is installed at the RFQ entrance to facilitate proper focusing and alignment of the beam. The central plate of the 5-segment cup has a diameter of ~ 10 mm (or a surface of [illegible]0 mm^2). The four outer segments have an outer diameter of 28.5 mm (or a surface of 139 mm^2 each). Another faraday cup, directly behind the ECR source, gives information about the total extracted ion beam.

Bellows provide the mechanical isolation of the ECR ion source, the 90° magnet, the focusing lenses and the RFQ, making it possible to independently align every element. Two turbo pumps with a total pumping speed of 500 l/s provide a pressure better than $2 \cdot 10^{-7}$ mbar in the LEBT area.

2. c) RFQ-Accelerator

The ECR source operates at a nominal potential of 15 kV, providing an O^{6+} beam of 5.6 keV/u. The RFQ linac accelerates this beam to 139.5 keV/u, the energy required for optimal injection into Linac 1 in the 2 $\beta\lambda$-mode. The RFQ provides a normalized transverse acceptance for 0.9 π mm mrad, and bunches the beam into a longitudinal phase space area of less than 0.28 MeV/u degree. The transverse acceptance requirement is set conservatively with respect to the brightness characteristics of the ECR source to ensure high transmission. The output longitudinal phase space specification, together with the operating frequency of 202.56 MHz, are driven by the requirements of Linac 1. Fig. 7 shows a cross sectional view of the RFQ accelerator.

The mechanical design of this RFQ is similar to the heavy ion RFQ also developed at LBL for use at the Bevatron[7]. It is a four vane, loop-driven structure with each vane mounted on supports which penetrate the cavity wall to give precise and reproducible positioning (Fig. 8). The vanes and cavity are made of copper plated, low carbon steel. A pumping speed in the cavity on the order of 500 l/s to maintain a pressure in the 10^{-7} mbar range is generated by two cryogenic pumps. The total length of the RFQ is 858 mm.

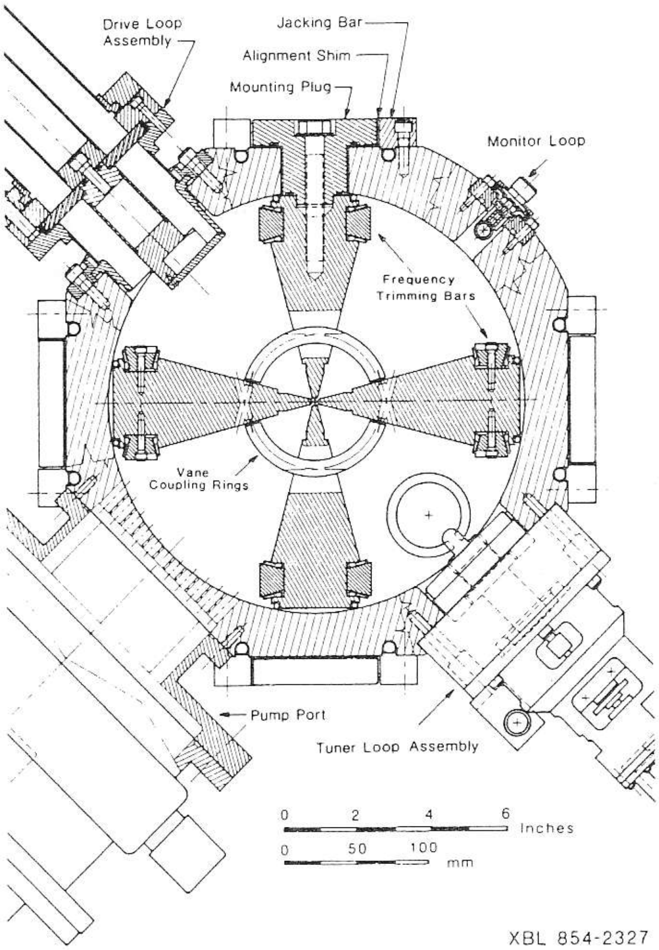


Fig. 7: Composite cross sectional view of the RFQ

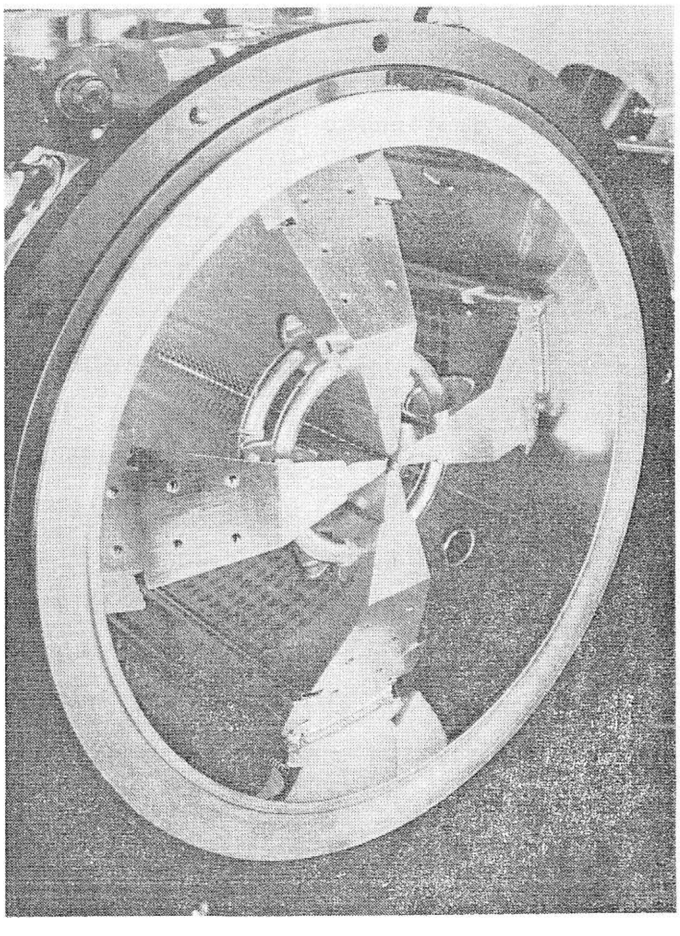


Fig. 8: RFQ four vane structure

The vane-vane voltage required for operation with O^{6+} is 35.6 kV. The theoretical Q value is 10900 with ideal copper walls and no joint losses. The actual operating Q is approximately 5500, due to the RF joints, to imperfections in the copper plating, and other factors. With this value of Q, the peak power demand is about 21 kW. The average power dissipation at a duty factor of less than 0.001 is a few watts. The temperature stabilisation of the cavity is achieved entirely by water flowing through copper tubes fixed to the outside of the tank. The basic parameters of the RFQ are summarized below:

Table: RFQ Parameters

Design ion	$^{16}O^{6+}$
Theoretical transmission	95 %
Frequency	202.56 MHz
T_{in}	5.625 keV/u
T_{out}	139.5 keV/u
Length	858 mm
R_o (aperture)	2.10 mm
No. of cells	169
Vane-vane voltage	35.6 kV
Peak rf power	21 kW (at Q = 5500)
Transverse acceptance	$\pi\varepsilon_n(x) = 0.9\ \pi$ mm mrad
	$\pi\varepsilon_n(y) = 0.9\ \pi$ mm mrad
Output phase spread	$\pm 23°$
Output energy spread	$\pm$ 4.3 keV/u

More detailed descriptions of the oxygen RFQ are given in Ref. 3 and 8. To match the beam from the RFQ to Linac 1, two rebuncher cavities are located between the RFQ and Linac 1. They are similar in design to the buncher used for the CERN proton RFQ[9]. Fig. 2 shows the location of these bunchers and the revised, off axis arrangement of the p-RFQ. The proton beam is bent by a 30° magnet and matched by several quadrupoles to a 60° inflector magnet. Magnets and lenses are pulsed, which would even allow parallel operation of the two injectors.[12]

3. Results of Tests at GSI and CERN

Measurements of ion beam intensity and quality have been undertaken with the ECR source alone, after the LEBT at the RFQ entrance point, and after the RFQ, including energy and energy spread measurements after a second bending-magnet.

3. a) ECR Ion Source and LEBT

The ECR ion source creates highly charged ions not by means of high density of of the source plasma, but by means of good ion containment in a step by step ionisation process. Thus about 30 ms are required to build up the maximum O^{6+} ion current of 80 - 100 µA in pulsed operation (Fig. 9). Moreover, the decay of higher charge states gives an afterglow output (after turn off of the microwave power) of the lower charged ions O^{+}, O^{2+}, O^{3+} (Fig. 10 a-c). For comparison, this is not seen for O^{5+} or He^{2+} (Fig. 10 d, e). Typical charge-state spectra for operation of the source with oxygen alone and with helium as an auxiliary gas are shown in Fig. 11a and b. The O^{6+} current increases by a factor of 1.5 to 2 with the introduction of auxiliary gas, the O^{5+} is similar in both cases, He^{+} is added to the O^{4+} peak, O^{7+} is visible and a certain amount of He^{2+} appears.

After proper adjustment of oxygen and helium gas flow and after a few hours conditioning time of the source, the helium valve only has to be adjusted a few times. For best O^{6+} production the magnetic field has to be at the highest possible level in the first stage and approximately 10 % lower in the second stage and in the extraction area. For proper O^{6+} production, 600 W - 800 W of microwave power are fed into the ECR source. After the first adjustment of the magnetic field and the microwave power no further corrections are necessary during source operation. This makes ECR ion source operation easy and reliable.

As mentioned above the ions are extracted from the source with 15 kV through a 7 mm Ø hole with an extraction electrode of 13 mm Ø over a gap width of 30 mm. The extraction geometry is shown in Fig. 12 together with calculated beam trajectories. The calculations of the beam formation and transport have been carried out with the AXCEL-GSI program[10] for a total ion current of 2 mA (measured) and an average charge of 3^{+}. The AXCEL program also gives values of the emittance of the source. Fig. 13 shows the emittance of the O^{6+} ion beam measured behind the 90° magnet together with the calculated emittance (74 π mm mrad). The agreement is obvious except for the aberrations (S shape).

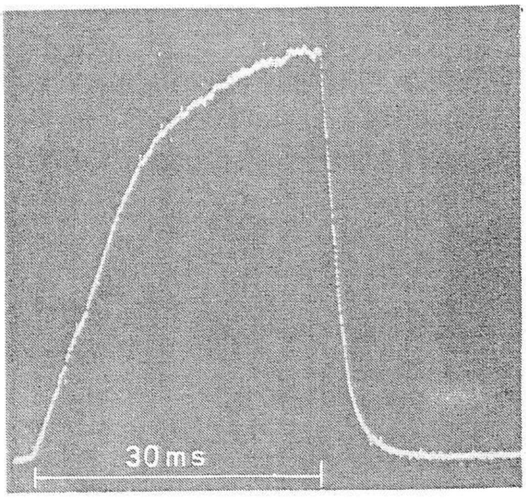


Fig. 9: Faraday cup signal of
80 μA O^{6+} at RFQ entrance

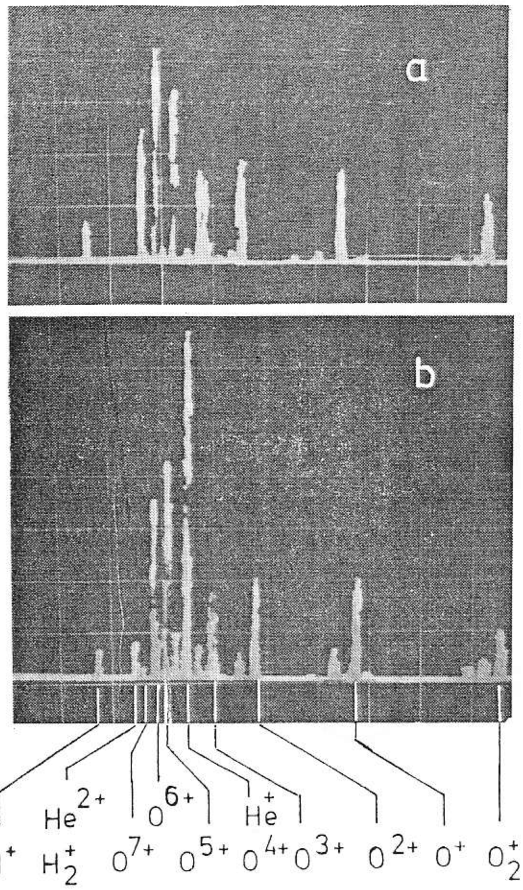
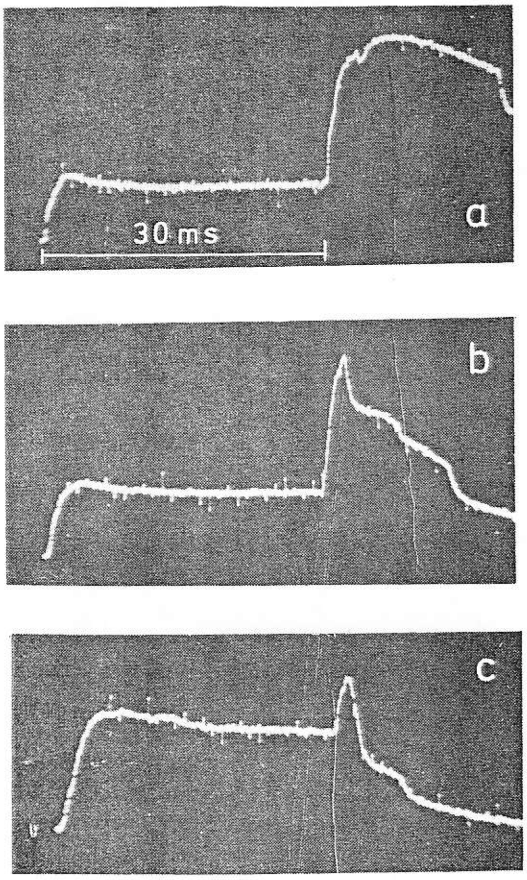


Fig. 11:
Typical charge spectrum for ECR ion source. Microwave power 800 W, 25 μA/div.
a) with oxygen gas only
b) with He as auxiliary gas



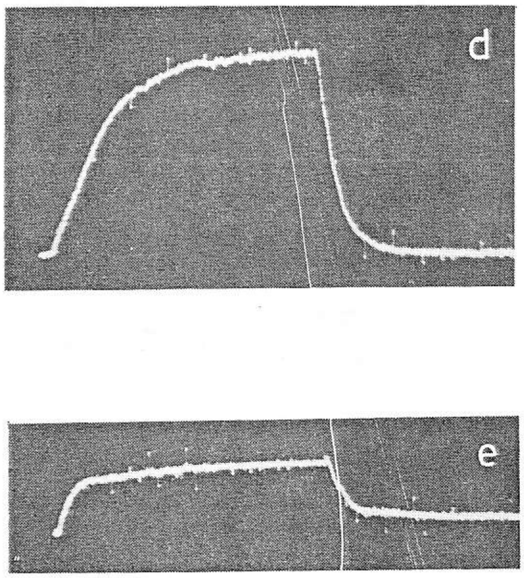


Fig. 10: Faraday cup signals for various ion species a) 10 μA O^{+}; b) 12 μA O^{2+}, c) 24 μA O^{3+}; d) 90 μA O^{5+}; e) 10 μA He^{2+} + H_2^{+}

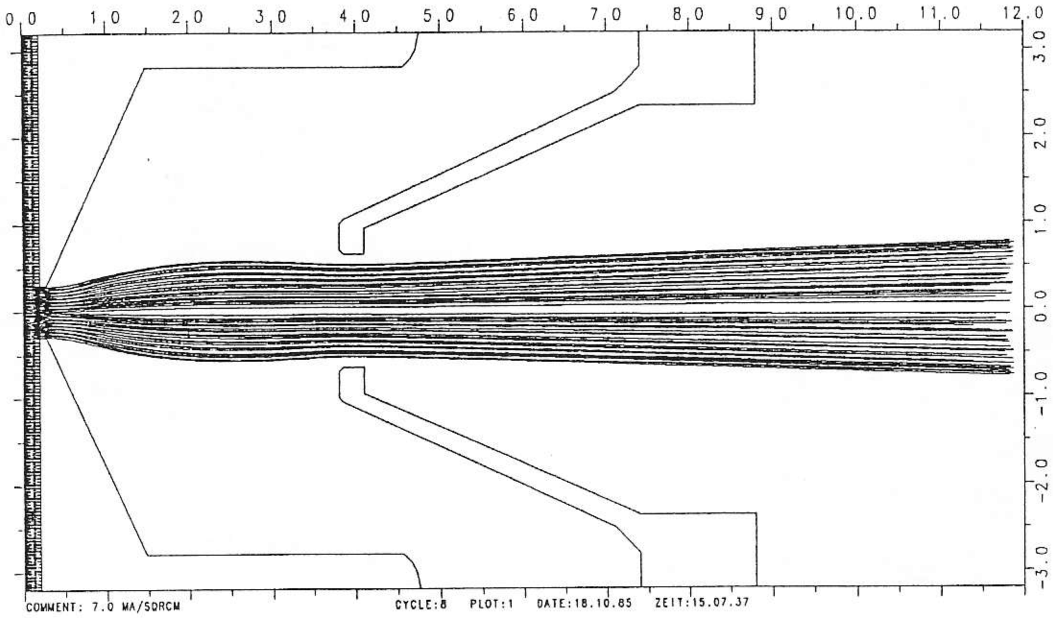


Fig. 12: Calculated beam trajectories for ECR ion source; extraction geometry 7 mm Ø and 13 mm Ø, total current 2.5 mA

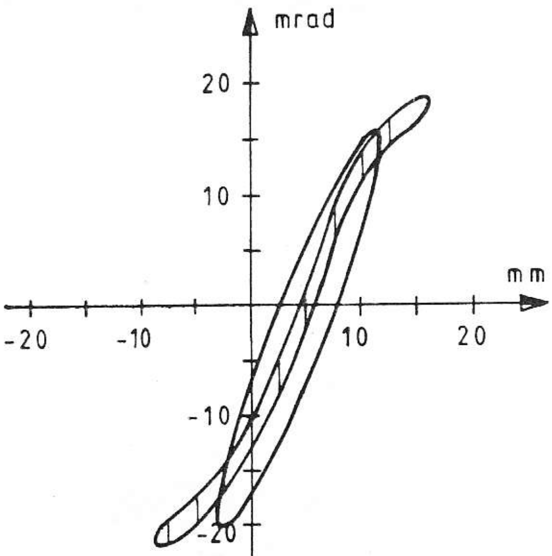


Fig. 13:
Measured (hatched) and calculated (74 π mm mrad) emittance for ECR ion source

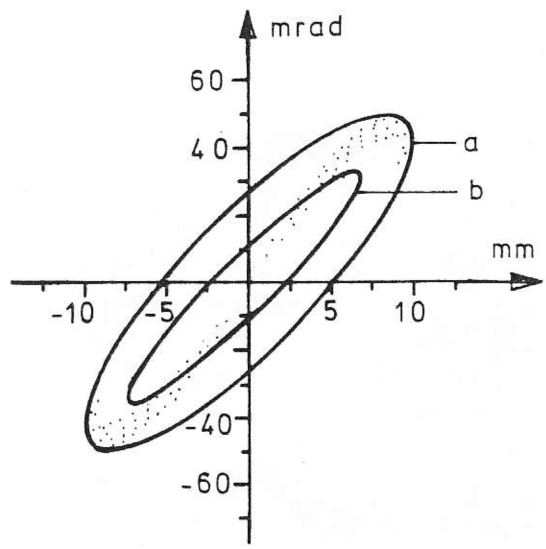


Fig. 14:
Calculated emittances 10 cm after extraction
a) extraction 9 mm Ø and 15 mm Ø (240 π mm mrad)
b) extraction 7 mm Ø and 13 mm Ø (74 π mm mrad)

Ion trajectories and the emittance for larger apertures of 9 mm Ø and 15 mm Ø respectively (gap width and extraction voltage unchanged) were calculated in the same way. Fig. 14 shows the emittance (240 π mm mrad), a value which should be accepted by the LEBT, increasing the O^{6+} current by a factor of 1.5 - 2. After installation at CERN it was demonstrated that a substantial increase in ion current could be reached (up to 130 μA) and that most of this beam could be matched to the RFQ (~ 100 μA).

With the grid (24 x 24 wires, distance 1.5 mm) in front of the second solenoid the beam profile could be measured for adjustment of the quadrupoles. A typically "good" profile for O^{6+} is shown in Fig. 15. The slightly oval beam (12 mm to 17 mm) is then finally focused by the second solenoid to less than 8 mm at the RFQ entrance, where the 5-segment faraday cup facilitates focusing and alignment of the beam. Fig. 16 shows a typical signal from the five segments; less than 5 % of the beam goes to the outer segments (up to 20 % in the case of the larger ECR extraction geometry now installed at CERN).

During the test measurements at GSI up to 100 eμA O^{6+} ions were observed with the specified beam quality in a very stable operating regime of the ECR ion source (8 hours without readjustment). This value could be verified after installation of the oxygen injector at CERN, where even higher O^{6+} currents could be reached with the larger ECR extraction geometry.

3. b) RFQ Accelerator

The 5.6 keV/u ion beam from the ECR source was accelerated by the RFQ to 139.5 keV/u. The RF power of 21 kW at a frequency of 202.56 MHz is delivered by an RF generator built by CERN, and coupled into the RFQ resonator by a single loop. Frequency tracking was accomplished using a single rotating loop which was manually adjusted during the tests when necessary (i.e. when the reflected power increased by a factor of 2-3 above the minimum value of appr. 50 W). The loop can also be adjusted by means of a motor permitting automatic control of the frequency tracking. The RFQ was operated in a pulsed regime with 1 pulse per second and 500 μs pulse length (200 μs is the normal pulse length at CERN, see Fig. 25). The RFQ generator was operated in a closed loop regime to overcome beam-induced locking during excitation of the RFQ resonator. In summary, the operation of the RFQ was simple and problem-free.

Various measurements were undertaken to measure the beam characteristics downstream of the RFQ. Some measurements were made directly after the RFQ (i.e. 32 cm from the vanes), and others downstream of a 77° analyzing magnet.

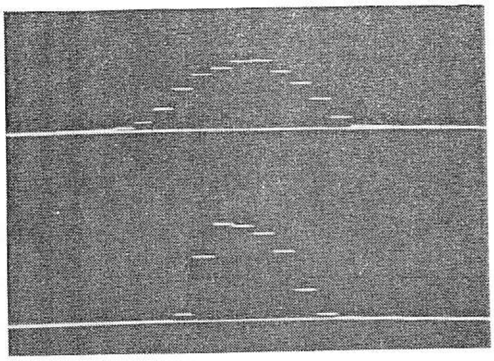


Fig. 15:
"Good beam profile" before solenoid 2 (1.5 mm/wire)

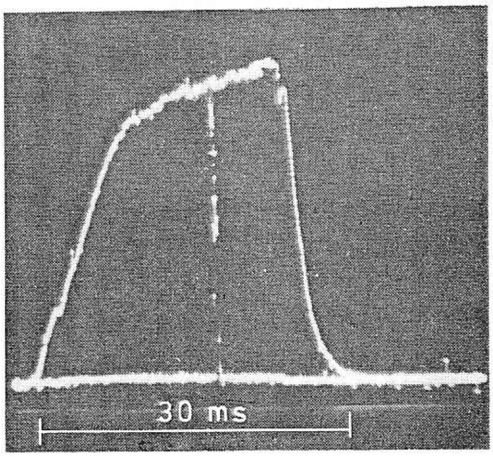


Fig. 17:
Faraday cup signal 80 µA O^{6+} at RFQ entrance (30 ms) and exit (500 µs)

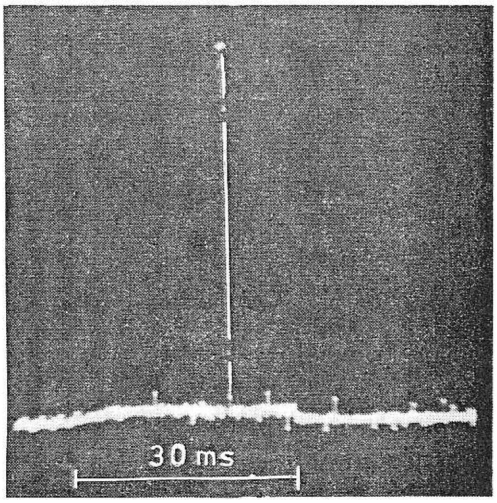


Fig. 19:
Faraday cup signal after RFQ with 500 µs, 80 µA accelerated beam and 30 ms, 2 µA drifting beam

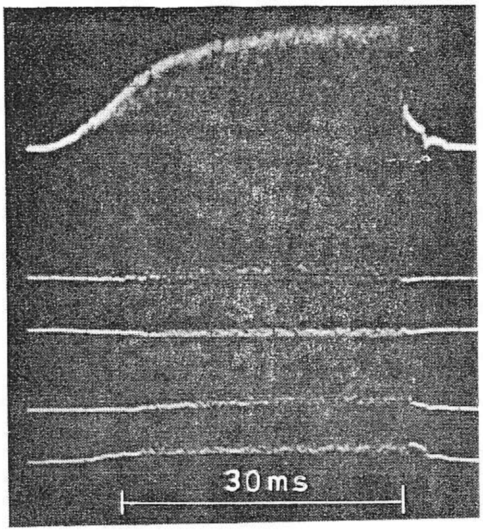


Fig. 16:
Typical 5-segment cup signals. Top 70 µA on center plate bottom 1 - 2 µA on outer segments

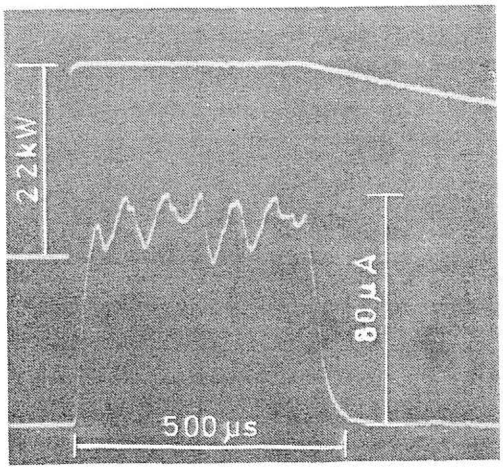


Fig. 18:
Faraday cup signal 80 µA O^{6+} at RFQ exit (500 µs) and control loop signal ~ 22 kW RF power (top)

The ion beam is accelerated through the RFQ without loss; when 80 eμA O^{6+} were injected into the RFQ, 80 eμA came out (Fig. 17). The beam is partly modulated with 10-20 KHz caused by oscillations of the ECR ion source plasma (Fig. 18). While the onset of the ion beam pulse from the ECR-source is determined by the onset of the microwave pulse, a jitter of a few ms could be observed at the end of the O^{6+} pulse. This was most probably due to plasma starvation for optimized gas flow. Therefore the RF-pulse for the RFQ was set between 20 and 25 ms after the start of the 30 ms ion source pulse (Fig. 17). Fig. 19 shows the ion signal at the faraday cup behind the RFQ with the part of the injected beam (2.5 %) drifting through the RFQ (30 ms) and the accelerated peak of 500 μs with full intensity.

The emittance of the ion beam coming from the RFQ was measured with a pepper pot device 32 cm after the end of the vanes. The exposure time was 1 hour, which also demonstrated the excellent stability of the system. Fig. 20 gives the emittances for 80 % of the beam in horizontal and vertical planes. They agree well with the emittances (100 %), calculated for the RFQ and also shown (39 π mm mrad).

To measure the bunch structure of the accelerated beam a 50 Ω coaxial faraday cup was installed at the position of the emittance meter. Fig. 21 shows the result of these measurements: no bunch structure at low RF power (or vane potential) (Fig. 21a); growing bunch structure when the power is increased to 20 kW (Fig. 21b); good bunch structure from the design power of 21 kW up to 24 kW (Fig. 21c), and vanishing bunch structure at higher power levels (Fig. 21d). Since the bunch measurements were done after a drift of 32 cm, the beam was already debunched again and the bunch signal is accordingly smoothed out. Operation of the RFQ was possible up to 35 kW, so that also acceleration of O^{5+} was also possible.

To measure the energy and the energy spread of the accelerated beam, a 77° analyzing magnet was installed downstream of the RFQ (Fig. 22). Due to imperfections of the analysing system, the energy could only be measured with 2 % accuracy. The resulting 140 keV/u are in agreement with the RFQ design energy of 139.5 keV/u. The energy spread was determined from the line width in the focal plane of the magnet, which was measured with a profile grid, a Kapton foil and an emittance meter to ca. 15 mm. This gives a value for the energy spread $\Delta W/W$ of ca. 2.5 % or ± 3.5 keV/u for 80 % to 90 % of the beam. For comparison the calculated energy spread of the RFQ (100 %) is 2.9 % or ± 4.3 keV/u.

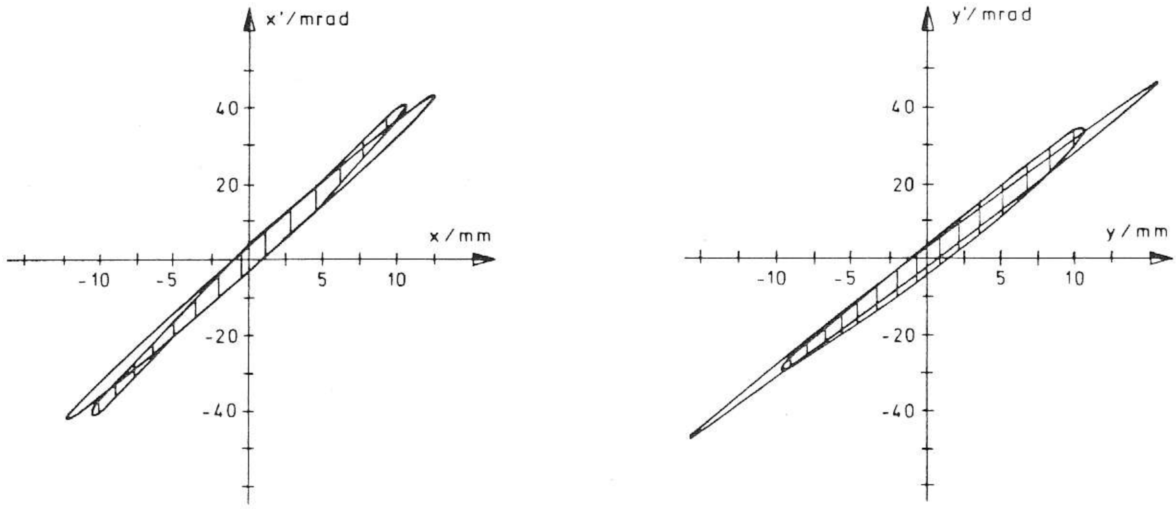


Fig. 20: Measured (hatched) and calculated emittances 32 cm after RFQ in horizontal (x) 39 π mm mrad and vertical (y) 32 π mm mrad planes

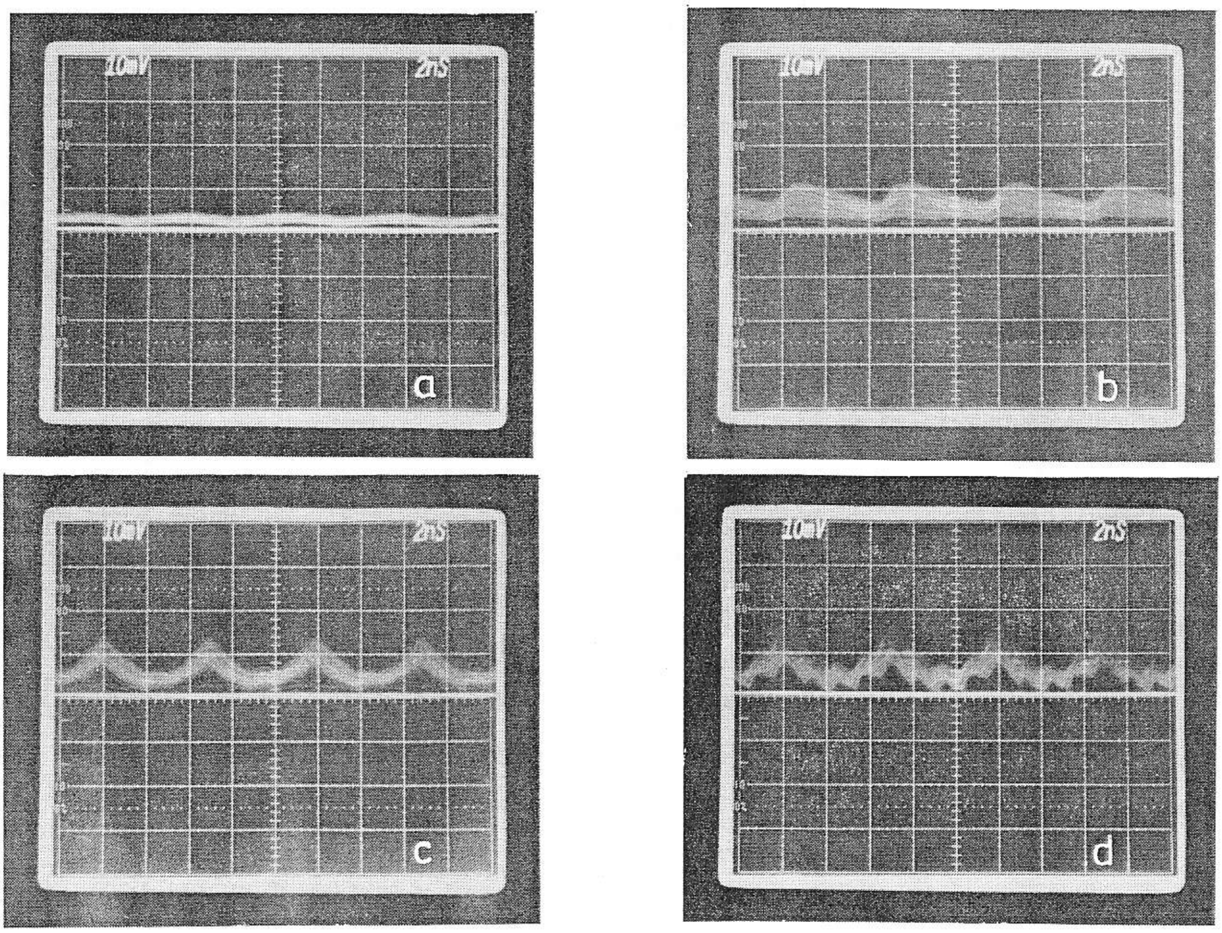


Fig. 21: Time structure (2 ns/div) of the accelerated ion beam 32 cm behind the RFQ for increasing RF power levels a - d.
C is for optimum conditions (200 μA/div)

In addition, beam intensity and energy distribution were also measured for various RF power levels between 16 kW (minimum field for acceleration) and 30 kW (starting of instabilities). Fig. 23 shows the result: at low power levels, the energy is shifted to somewhat lower values, the beam intensity is reduced and the energy distribution is skewed toward lower energies. At the design power of 21 kW the maximum ion intensity is reached at the design energy of approximately 140 keV/u. Reduction of beam intensity is also observed for power (or field) levels higher than the optimum, combined with a broader but still symmetric energy distribution. These observations are consistent with previous measurements on a proton RFQ reported in ref. 11. Fig. 24 shows the transmission curve of the RFQ for O^{6+} injected with 5.6 keV/u as a function of the RFQ RF power. The transmission drops down from 100 % at 21 kW to 30 % at 10 kW and then decreases slowly to near zero. The ions coming through the RFQ at power levels below 15 kW are more or less unaccelerated and only guided through the RFQ channel by the RF field as can be seen from the low magnetic field of 820 G (required in the 77° analyzing magnet), at which strength most of the ions can be detected, instead of 4.1 KG for the accelerated beam.

3. c) Tests at CERN

After transport to CERN the oxygen injector was installed at Linac 1. First tests showed similar or (with the larger extraction aperture) even better results than at GSI. Up to 100 eμA O^{6+} could be detected with the coaxial faraday cup (Ø 15 mm) downstream of the first buncher. The buncher RF broke down during the first tests when the ion beam was switched on. Even after a delay of 50 μs for the RFQ (Fig. 25) it was not possible to get a stable operation until the beam was chopped before the RFQ by applying a pulsed voltage to the isolated vertical slit after the 90° magnet (see Fig. 2). In this way, the unaccelerated ion beam (30 ms) drifting through the RFQ (see Fig. 19) and causing the buncher problems, could be suppressed.
Preliminary tests with Linac 1 (in Febr./March 1986) showed that it is possible to reach the right RF amplitudes to accelerate and transport up to 10 μA O^{6+} through tank 1 (without optimization of the buncher parameters) but it was not yet possible to reach stable conditions for oxygen acceleration. Additional tests were run with α-particles - from the ECR source and accelerated at lower RFQ RF levels to the injection energy of 140 keV/u - to verify

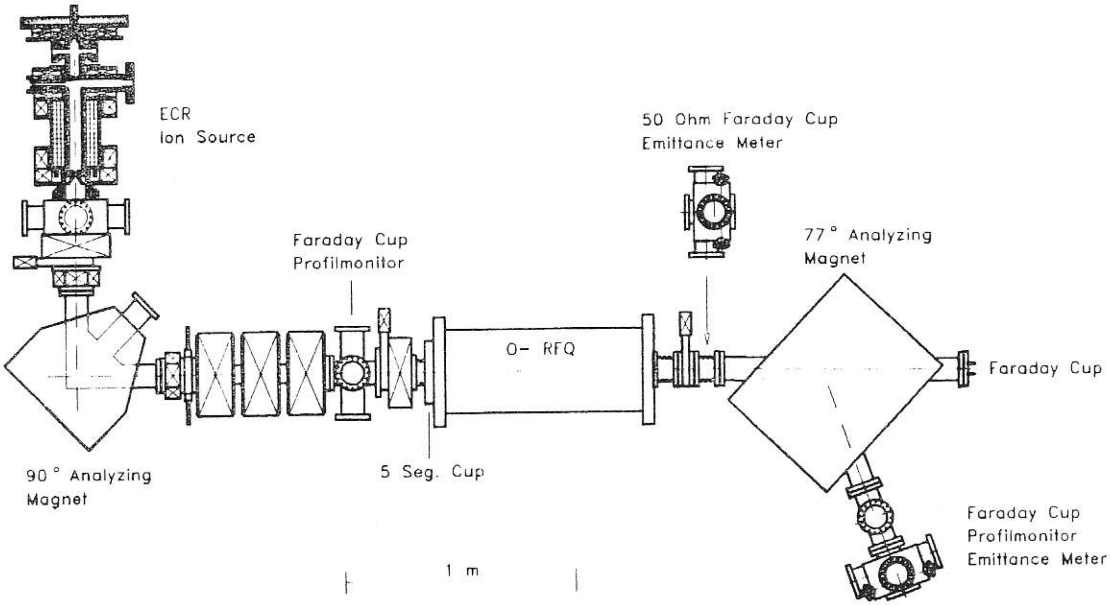


Fig. 22: Experimental set up for ion beam energy measurements

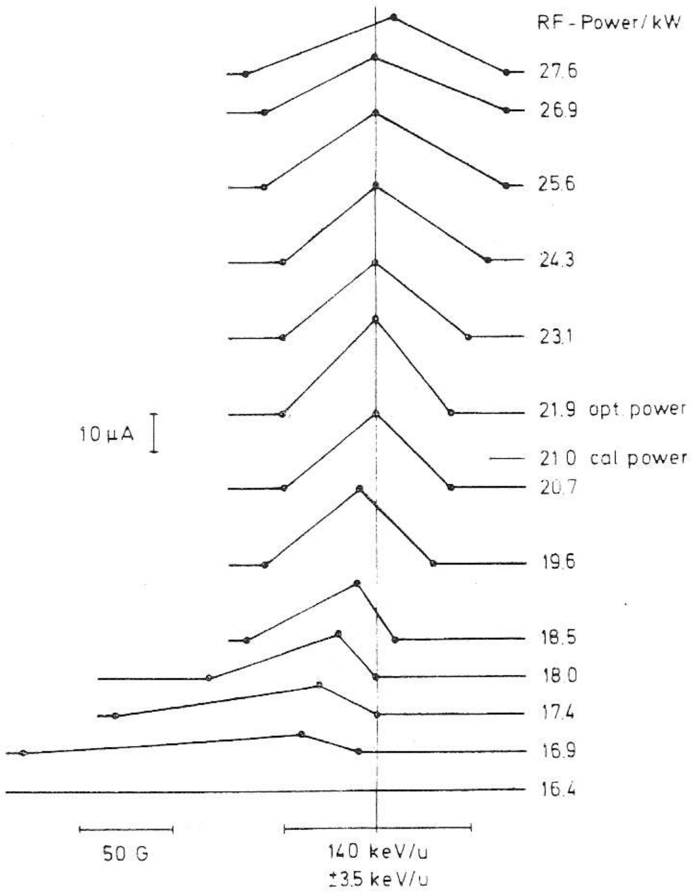


Fig. 23:
Energy distribution of accelerated ion beams at different RF power levels of the RFQ

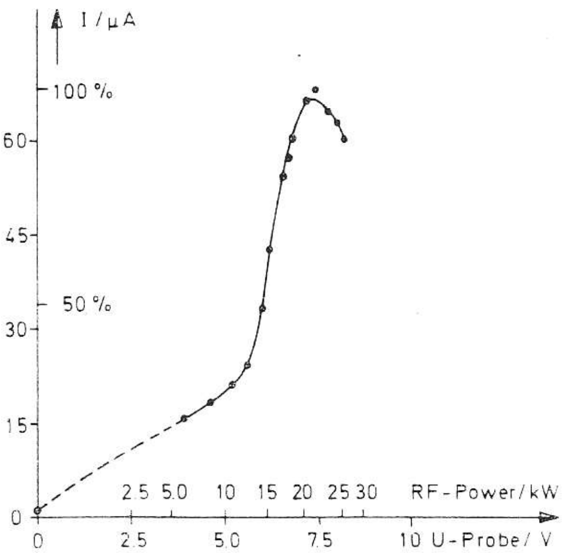


Fig. 24:
Transmission characteristic of RFQ

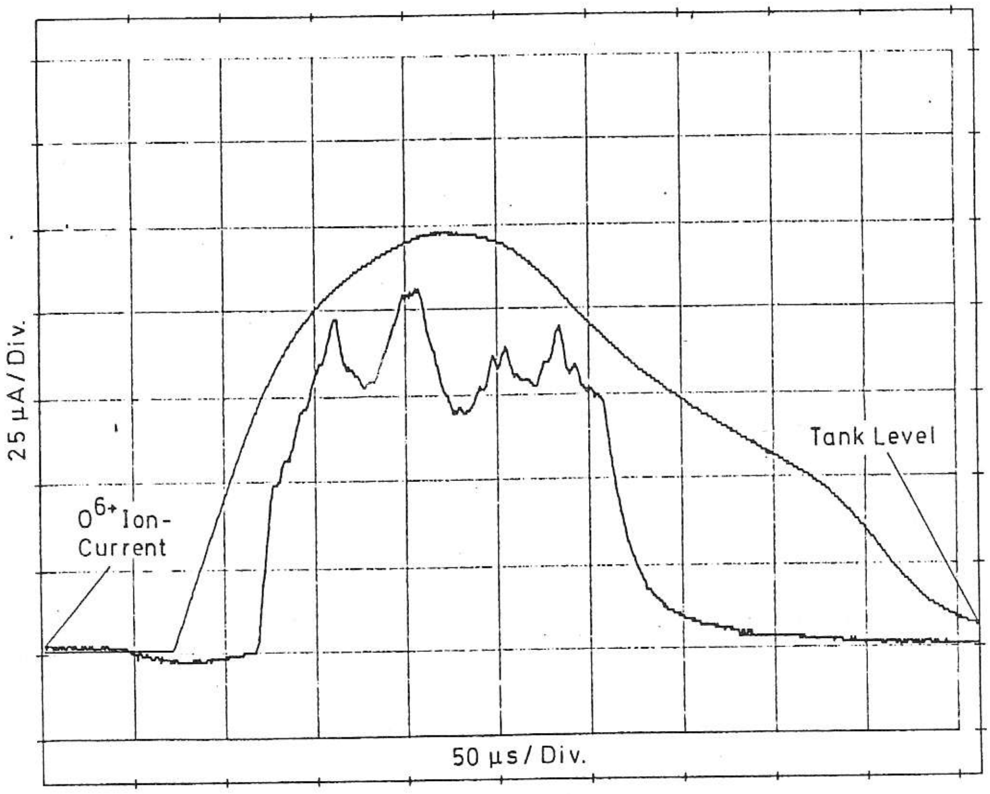


Fig. 25: Time structure of O^{6+} ion beam downstream from the O-buncher and RF signal of Linac tank 1. (RF of O-buncher starts with Linac RF; RF of RFQ with 50 µs delay)

the optimal levels for the Linac RF amplitudes and for the quadrupole fields in the linac and along the transfer line to the booster ring.[12]

Further tests with oxygen beams will be carried out during 1986. Two experimental runs of 18 days each with PS and SPS are scheduled for end of 1986 and mid of 1987.

4. Conclusions

It was proven that the oxygen injector for the CERN Linac 1 reached all its design values, i.e. 80 eμA O^{6+} ions could be detected at an energy of ca. 140 keV/u with an energy spread of ± 3.5 keV/u. The oxygen injector is very stable in operation and an extremely reliable machine. After conditioning and adjustment over 1-2 days it runs stably over days with only slight corrections of the He support gas pressure. No break down occurred during the test period of 4 months. First tests with Linac 1 showed that it is possible to accelerate O^{6+} ions to the required energy of 12.5 MeV/u.

Acknowledgement

The authors wish to acknowledge the substantial help of M. Pontonier during the ECR construction at Grenoble, of G. Jöst and H. Gebhardt and the other GSI coworkers, who all helped to get the injector running in time and with such excellent results. In addition, the valuable support from H. Charmot during the installation at CERN is gratefully acknowledged. The coordinator of the project in addition would like to thank all the people involved in this project especially the colleagues in Grenoble (R. Geller and B. Jacquot), Berkeley (R. Gough and J. Staples) and Geneva (H. Haseroth and Ch. Hill) for the excellent cooperation and information which helped to make this multi-national project so successful. Proof of this was the fact that the ECR ion source and the RFQ could be connected to the LEBT without corrections despite all the differences of norms, fabrication and design traditions in the different countries. Finally the support and patience in the preparation of the manuscript by K. Möller, P. Mellick, and N. Stanton should be mentioned.

References

[1]R. Stock et al. "Study of Relativistic Nucleus-Nucleus Reactions Induced by ^{16}O Beams of 9-13 GeV per nucleon at the CERN PS", Proc. of the Bielefeld Workshop on Quark Matter Formation and Heavy Ion Collisions, may 1982, p.557, Edit. M. Jacob and H. Satz (1982).
[2]H. Haseroth "Light Ions at CERN", ibid.
[3]N. Angert et al. "A Heavy Ion Injector for CERN Linac 1", Proc. of the 1984 Linear Accelerator Conf., Seeheim (Germany), p.374, Edit. N. Angert, report GSI-84-11, GSI-Darmstadt 1984.
[4]R. Geller et al."The MINIMAFIOS Status 1985", Proc. of the 6th Int. Workshop on ECR Ion Sources, Berkeley 1985, Edit. C.Lyneis, report PUB-5143, LBL Berkeley 1985 and Nucl. Instr. Meth. A243, 244 (1986).
[5]R. Stock "The CERN Heavy Ion Program", Proc. of the 2nd Int. Conf. on Nucleus-Nucleus Collisions, Visby (Sweden) 1985 and report GSI-85-40, GSI-Darmstadt 1985.
[6]R. Geller and B. Jacquot, Nucl. Instr. Meth. 202, 399, (1982).
[7]J. Staples et al. "Initial Operation of the LBL Heavy Ion RFQ", Conf. on High-Energy Accelerator, Batavia, IL, USA, August 1983.
[8]R. Gough et al. "A Compact Heavy Ion RFQ Preaccelerator for Use at the CERN Linac 1", Proc. of the Particle Accelerator Conf., Vancouver 1985.
[9]E. Boltezar et al. "Performance of the CERN RFQ (RFQ 1 Project)", Proc. of the 1984 Linear Accelerator Conf. Seeheim (Germany), p.56, Edit. N. Angert, report GSI-84-11, GSI Darmstadt 1984.
[10]P. Spädtke "The AXCEL-GSI code", report GI-83-9, GSI Darmstadt 1983.
[11]O.R. Sanders et al. "Operational Parameters of a 2.0 MeV RFQ Linac", Proc. of the 1984 Linear Accelerator Conf., Seeheim (Germany), p.54, Edit N. Angert, report GSI-84-11, GSI Darmstadt 1984.
[12]H. Haseroth et al., Ion acceleration in the CERN Linac 1 to be presented at the 1986 Linac Conference, Los Alamos, USA.